Materials Science of Thin Films

Deposition and Structure

Second Edition

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generally reveals good agreement. Significantly, this simplified collisional model reproduces trends in experimental data for the projectile energy, mass, and target dependence of the sputter yield.

4.5.2.3 Sputtering of Alloys

In contrast to the fractionation of alloy melts during evaporation, with subsequent loss of deposit stoichiometry, sputtering allows for the deposition of films having the same composition as the target source. This is a primary reason for the widespread use of sputtering to deposit metal alloy films. We note, however, that each alloy component evaporates with a different vapor pressure and sputters with a different yield. Why, then, is film stoichiometry maintained during sputtering and not during evaporation? One reason is the generally much greater disparity in vapor pressures compared to the difference in sputter yields under comparable deposition conditions. Secondly, and more significantly, melts homogenize readily because of rapid atomic diffusion and convection effects in the liquid phase; during sputtering, however, minimal solid-state diffusion enables the maintenance of the required altered target surface composition.

Consider now sputtering effects (Ref. 16) on a binary-alloy target surface containing a number of A atoms (n_A) and B atoms (n_B) such that the total number is $n = n_A + n_B$. The target concentrations are $C_A = n_A/n$ and $C_B = n_B/n$, with sputter yields S_A and S_B. Initially, the ratio of the sputtered atom fluxes (ψ) is given by

$$\frac{\psi_A}{\psi_B} = \frac{S_A C_A}{S_B C_B}. \tag{4-39}$$

If n_g sputtering gas atoms impinge on the target, the total number of A and B atoms ejected are $n_g C_A S_A$ and $n_g C_B S_B$, respectively. Therefore, the target surface concentration ratio is modified to

$$\frac{C'_A}{C'_B} = \frac{C_A\,(1 - n_g S_A/n)}{C_B\,(1 - n_g S_B/n)} \tag{4-40}$$

instead of C_A/C_B. If $S_A > S_B$, the surface is enriched in B atoms, which now begin to sputter in greater profusion, i.e.,

$$\frac{\psi'_A}{\psi'_B} = \frac{S_A C'_A}{S_B C'_B} = \frac{S_A C_A(1 - n_g S_A/n)}{S_B C_B(1 - n_g S_B/n)}. \tag{4-41}$$

Progressive change in the target surface composition lowers the sputtered flux ratio to the point where it is equal to C_A/C_B, which is the same as the original target composition. Simultaneously, the target surface reaches the value $C'_A/C'_B = C_A S_B/C_B S_A$, which is maintained thereafter. A steady-state transfer of atoms from the bulk target to the plasma ensues resulting in stoichiometric film deposition. This state of affairs persists until the target is consumed. Conditioning of the target by sputtering a few hundred layers is required to reach steady-state conditions. As an explicit example, consider the deposition of Permalloy films having the atomic ratio 80 Ni–20 Fe from a target of this same composition. Using 1 keV Ar, the sputter yields are $S_{Ni} = 2.2$ and $S_{Fe} = 1.3$. The target surface composition is altered in the steady state to $C_{Ni}/C_{Fe} = 80(1.3)/20(2.2) = 2.36$, which is equivalent to 70.2 Ni and 29.8 Fe.

4.5.2.4 A Potpourri of Sputtering Results and Effects

Over the years a large number of interesting experimental observations have been made with regard to sputtering effects. The influence of sputtering gas and ion energy have already been discussed. Other phenomena and results are listed next in no particular order.

1. *Effect of periodic table.* Sputter yields were measured for metal elements in given rows of the periodic table using 400 eV Ar ions (Ref. 17). In the sequence Zr, Nb, Mo, Ru, Pd, and Ag, there was a continuous rise in S from ~0.5 to about 2.7. Similar, although smaller, increases in S were observed for those elements lying in the row between Ti and Cu, as well as the row between Ta and Au. The well-known strong inverse variation between S and sublimation energy is apparent in these results. In a similar vein, the previously noted correlation between threshold energy (E_{th}) and sublimation energy (U_S) has been roughly verified for many metals, i.e., $E_{th} \simeq 5U_S$.
2. *Crystallographic effects.* Studies of ion-bombarded single crystals reveal that atom emission reflects the lattice symmetry. In FCC metals it has been demonstrated that atoms are preferentially ejected along the [110] direction, but ejection in [100] and [111] directions also occurs to lesser extents (Ref. 18). For BCC metals [111] is the usual direction for atom ejection. These results are consistent with the idea that whenever a beam sees a low density of projected lattice points the ions penetrate more deeply, thus reducing S. Such observations on single crystals confirmed momentum transfer as the mechanism for atomic ejection; the notion of ion-induced melting and evaporation of atoms was dispelled because preferred directions for sublimation of atoms are not observed.